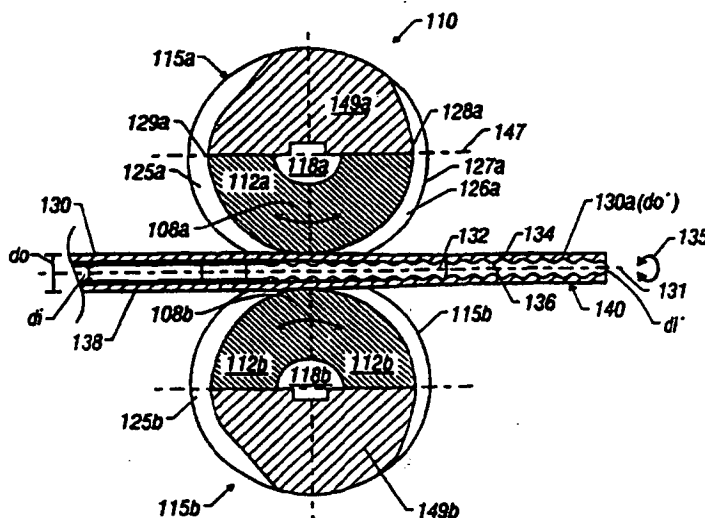


(21) (A1) **2,315,043**

(86) 1998/12/17

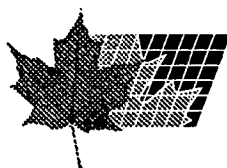
(87) 1999/06/24

(72) KRUEGER, VOLKER, DE  
(72) WALTERSKOETTER, MARKUS, DE  
(72) REGENER, THORSTEN, DE  
(71) BAKER HUGHES INCORPORATED, US  
(51) Int.Cl.<sup>6</sup> F04C 2/107, B21C 37/00  
(30) 1997/12/18 (60/068,090) US  
(54) **PROCEDE DE FABRICATION DE STATORS POUR POMPES DE  
TYPE MOINEAU**  
(54) **METHODS OF MAKING STATORS FOR MOINEAU PUMPS**



(57) Cette invention concerne des procédés de fabrication de moteurs de forage. Selon un premier procédé, des cylindres sont violemment poussés contre un élément tubulaire dans lequel se trouve un mandrin dont le profil extérieur est l'inverse du profil désiré du stator. Selon un deuxième procédé, des cylindres sont poussés et mis radialement en rotation sur l'élément tubulaire dans lequel se situe le mandrin. Selon un troisième procédé, des matrices sont poussées contre l'élément tubulaire

(57) The present invention provides methods of forming mud motors. In one method, rollers are urgingly stroked against a tubular member having a mandrel therein that has an outer profile which is the inverse of the desired profile of the stator. In another method, rollers are urged and rotated radially on the tubular member with the mandrel disposed in the tubular member. In yet another method, dies are pressed against the tubular member having a mandrel with a desired outer profile. In another



(21) (A1) **2,315,043**  
(86) 1998/12/17  
(87) 1999/06/24

comportant un mandrin ayant le profil extérieur désiré. Selon un quatrième procédé, un métal fondu est déposé sur un mandrin comportant une surface extérieure lobée qui est sensiblement l'inverse du profil intérieur désiré du carter de stator. Le mandrin est ensuite enlevé, ceci laissant la place à un élément longitudinal présentant un profil intérieur défini par le profil extérieur du mandrin. Le mandrin peut également être une crépine préformée d'une épaisseur désirée comportant des surfaces lobées internes et externes. Dans chacun de ces procédés, la surface interne de l'élément résultant présente le profil défini par le profil extérieur du mandrin. La surface interne de l'élément résultant peut ensuite être recouverte ou enduite d'un matériau approprié tel qu'un élastomère ou une céramique. La surface interne du stator peut également être métallique. Un rotor adapté est ensuite placé dans le stator pour former le moteur de forage.

method, a molten metal is deposited over a mandrel with an outer lobed surface that is substantially the inverse of the desired inner profile of the stator housing. The mandrel is then removed, leaving a metallic longitudinal member having an inner profile defined by the outer profile of the mandrel. The mandrel may also be a preformed liner of desired thickness having an inner and outer lobed surface. In each of these methods, the inner surface of the resulting member has the profile defined by the outer profile of the mandrel. The inner surface of the resulting member then may be coated or lined with a suitable material such as an elastomer or a ceramic. The stator inner surface may also be metallic. A suitable rotor is then disposed in the stator to form the drilling motor.





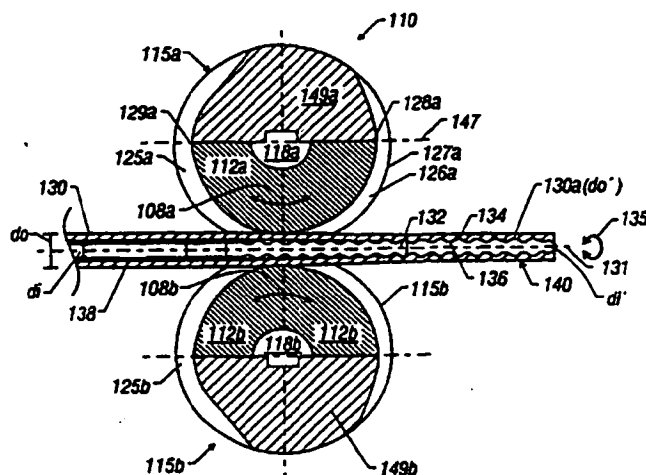
PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION  
International Bureau

## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification <sup>6</sup> : F04C 2/107, B21C 37/00	A2	(11) International Publication Number: WO 99/31389 (43) International Publication Date: 24 June 1999 (24.06.99)
(21) International Application Number: PCT/US98/26963 (22) International Filing Date: 17 December 1998 (17.12.98) (30) Priority Data: 60/068,090 18 December 1997 (18.12.97) US (71) Applicant: BAKER HUGHES INCORPORATED [US/US]; Suite 1200, 3900 Essex Lane, Houston, TX 77027 (US). (72) Inventors: KRUEGER, Volker; Sassengarten 8, D-28223 Celle- (DE). WALTERSKOETTER, Markus; Hauptstrasse 126d; D-29352 Adelheidsdorf (DE). REGENER, Thorsten; Piener Weg 82, D-31303 Burgdorf (DE). (74) Agents: ROWOLD, Carl, A. et al.; Baker Hughes Incorporated, Suite 1200, 3900 Essex Lane, Houston, TX 77027 (US).	(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW; ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).  Published Without international search report and to be republished upon receipt of that report.	

(54) Title: METHODS OF MAKING STATORS FOR MOINEAU PUMPS



## (57) Abstract

The present invention provides methods of forming mud motors. In one method, rollers are urgedly stroked against a tubular member having a mandrel therein that has an outer profile which is the inverse of the desired profile of the stator. In another method, rollers are urged and rotated radially on the tubular member with the mandrel disposed in the tubular member. In yet another method, dies are pressed against the tubular member having a mandrel with a desired outer profile. In another method, a molten metal is deposited over a mandrel with an outer lobed surface that is substantially the inverse of the desired inner profile of the stator housing. The mandrel is then removed, leaving a metallic longitudinal member having an inner profile defined by the outer profile of the mandrel. The mandrel may also be a preformed liner of desired thickness having an inner and outer lobed surface. In each of these methods, the inner surface of the resulting member has the profile defined by the outer profile of the mandrel. The inner surface of the resulting member then may be coated or lined with a suitable material such as an elastomer or a ceramic. The stator inner surface may also be metallic. A suitable rotor is then disposed in the stator to form the drilling motor.



NO 99/31389

PCT/US98/26963

**WHAT IS CLAIMED IS:**

1. A method of making a drilling motor for drilling wellbores, comprising:

- 5 (a) providing a metallic tubular member having a first outside diameter and made of a first material that is desired to be transformed to a stator housing having a desired inner profile along an axial direction;
- 10 (b) placing a mandrel axially inside the metallic tubular member, said mandrel having a contoured outer surface for defining the desired inner profile of the stator housing;
- 15 (c) applying compressive force radially over the metallic tubular member by a force application device to compress the tubular member toward the mandrel to produce the stator housing having the desired inner profile and a second outside diameter; and
- 20 (d) coating the inner surface of the stator housing with a second material that is different from the first material to form the stator of the drilling motor.

NO 99/31389

PCT/US98/26963

2. The method of claim 1, wherein the force application device includes at least two force application members that urge against the outer surface of the metallic tubular member to apply compressive force thereon.

5

3. The method of claim 2, wherein the at least two force application members are rollers that stroke axially over the metallic tubular member.

10

4. The method of claim 3, wherein each said roller travels a varying distance radially toward the metallic tubular member during each said stroke.

15

5. The method of claim 4 further comprising rotating the hollow tubular member while said at least two force application members stroke axially.

20

6. The method of claim 2, wherein said at least two force application members are rollers that rotate in same direction radially to apply the compressive force on the metallic tubular member.

7. The method of claim 3 further comprising rotating the metallic tubular member while the rollers are applying the compressive force against the metallic tubular member.

5 8. The method of claim 2 wherein said at least two force application members are swaging devices which substantially simultaneously urge against the outer surface of the metallic tubular member to compress the metallic tubular member toward the mandrel to form the stator housing.

10

9. The method of any of claims 1-8 wherein the second material is selected from a group consisting of (i) an elastomeric material, (ii) a thermo-plastic material, (iii) a ceramic material, and (iv) a metallic material.

15

10. The method of any claims 1-9 wherein the second material is applied on the inner surface of the stator housing by one of (i) a galvanic deposition process, (ii) an electrolytic deposition process, (iii) a molding process, (iv) a baking process, (v) a plasma spray process, and (vi) a thermo-set process.

20

WO 99/31389

PCT/US98/26363

11. The method of any of claims 1-10 wherein the second material includes at least two layers.

5 12. The method of any of the claims 1-11 wherein at least one of said layers is a resin material for bonding said second material to the stator housing.

10 13. The method of any of claims 1-12 wherein said coating is substantially uniform in thickness.

14. The method of any of claims 1-13, further comprising disposing a rotor having an outer contoured surface within said stator to form said drilling motor.

15 15. The method of any of claims 1-14 wherein said mandrel is tapered for easy removal of said mandrel from the stator housing.



## METHODS OF MAKING STATORS FOR MOINEAU PUMPS

**BACKGROUND OF THE INVENTION**

5

**1. Field of the Invention**

This invention relates generally to drilling or mud motors used for drilling wellbores and more particularly to methods of making such  
10 motors.

**2. Description of the Related Art**

To obtain hydrocarbons such as oil and gas, boreholes or  
15 wellbores are drilled by rotating a drill bit attached to a drill string end. A substantial proportion of the current drilling activity involves directional drilling, i.e., drilling deviated and horizontal boreholes, to increase the hydrocarbon production and/or to withdraw additional hydrocarbons from the earth's formations. Modern directional drilling systems generally  
20 employ a drill string having a drill bit at the bottom that is rotated by a motor (commonly referred to in the oilfield as the "mud motor" or the "drilling motor").

WO 99/31389

PCT/US98/26963

Positive displacement motors are commonly used as mud motors. United States Patent No. 5,135,059, assigned to the assignee hereof, which is incorporated herein by reference, discloses one such mud motor. A typical mud motor includes a power section  
5 which contains a stator and a rotor disposed in the stator. The stator typically includes a metal housing which is lined inside with a helically contoured or lobed elastomeric material. The rotor is usually made from a suitable metal, such as steel, and has an outer lobed surface. Pressurized drilling fluid (commonly known as the "mud" or "drilling  
10 fluid") is pumped into a progressive cavity formed between the rotor and stator lobes. The force of the pressurized fluid pumped into the cavity causes the rotor to turn in a planetary-type motion. A suitable shaft connected to the rotor via a flexible coupling compensates for eccentric movement of the rotor. The shaft is coupled to a bearing  
15 assembly having a drive shaft (commonly referred to as the "drive sub") which in turn rotates the drill bit attached thereto. Other examples of the drilling motors are disclosed in United States Patent Nos. 4,729,675, 4,982,801 and 5,074,681. Additionally, German Patent DE 4 111 162 shows a stator for a single lobe eccentric screw  
20 pump with a precontour wherein the rubber lining has gradually

WO 99/31389

PCT/US98/26963

changing thickness over the length of the stator and French Patent 2  
299 533 describes a method of making a stator wherein a tubular  
member is forced axially through a die that may include rollers to  
obtain a stator that has the inner and outer profiles defined by the  
5 mandrel.

As noted above, both the rotor and stator are lobed. The rotor  
and stator lobe profiles are similar, with the rotor having one less lobe  
than the stator. The difference between the number of lobes on the  
10 stator and rotor results in an eccentricity between the axis of rotation of

2A

AMENDED SHEET.

the rotor and the axis of the stator. The lobes and helix angles are designed such that the rotor and stator lobe pair seal at discrete intervals. This results in the creation of axial fluid chambers or cavities which are filled by the pressurized circulating fluid. The action of the  
5 pressurized circulating fluid causes the rotor to rotate and precess within the stator.

The rotor typically is made of a material such as steel and has an outer contoured surface which is relatively easily to manufacture with precision. The stator, however, has an inner lobed surface and is made  
10 of an elastomeric material, typically by an injection molding process. The thickness of the elastomer varies with the contour of the lobes. Manufacturing of stators requires detailed attention to elastomer composition, consistency, bond integrity and lobe profile accuracy. The stators of relatively large mud motors can be several feet long. Because  
15 of the stator's physical characteristics (length, lobe profile, etc.) and the precision required, stators are frequently made by joining smaller sections. Such manufacturing processes are time consuming, expensive and offer few flexibilities. Also, since the elastomeric layer is typically non-uniform, it exhibits uneven heat dissipation and wear characteristics.

20

Stators with relatively thin and uniform elastomeric layers tend to perform better and have longer operating lives than those of non-uniform

elastomeric stators described above. In some applications, completely metallic stators or having a non-elastomeric layer, such as a ceramic layer, may be preferred.

5           The present invention addresses certain problems with the prior art methods of making mud motors and provides methods for manufacturing mud motors, wherein the stator is made as a continuous member with inner surface having a desired profile, which is then lined with a substantially uniform layer of a suitable material such as an elastomeric  
10 or ceramic material. The methods of the present invention are efficient and cost effective.

#### SUMMARY OF THE INVENTION

15           The present invention provides methods of manufacturing mud motors. The motor includes a stator and a rotor which is rotatably disposed in the stator. In one method, to form the stator, a mandrel whose outer surface substantially corresponds to the inverse of the desired inner profile of the stator is disposed inside a metal tubular  
20 member. The mandrel has a slightly tapered end for easy retrieval from the tubular member. The metal tubular member with the mandrel therein is placed between at least two rollers disposed on opposite sides of the

tubular member. The rollers, while urging against the tubular member, rotate in opposite directions (one clockwise and the other counter-clockwise), thereby moving on the tubular member in the same direction.

These rollers rotate back and forth thereby stroking over the tubular  
5 member. This stroking motion reduces the outer dimensions of the tubular member. The tubular member is rotated about its longitudinal axis while the rollers stroke. The process is continued until the inside of the tubular member attains the profile defined by the outer profile of the mandrel. After a section of the tubular member is formed, the tubular  
10 member is moved axially to form the next section. The inside of the tubular member is then lined with a suitable material, such as an elastomer or a ceramic material. A suitable rotor having a desired outer lobed surface is then rotatably disposed in the stator to form the motor.

15 In an alternative method for manufacturing the mud motor, the stator is formed by compressing a tubular member by a plurality of continuously rolling rollers. A mandrel whose outer surface corresponds to the inverse of the desired inner profile of the stator is placed inside a metal tubular member. The mandrel has a slightly tapered surface for  
20 easy retrieval from the tubular member. A plurality of rollers are urged against the tubular member while rotating in a common direction, thereby rotating the tubular member in the direction opposite that of the rollers.

This rolling action reduces the outer dimensions of the tubular member. The process is continued until the inside of the tubular member attains the desired profile.

5        In yet another method of forming a stator, a tubular member having therein a mandrel with an outer contoured surface is alternately pressed with a plurality of dies disposed around the tubular member's outer surface, thereby reducing the outside dimensions of the tubular member. The process is continued until the inside surface of the tubular  
10 member attains the profile defined by the mandrel. The tubular member inside is lined with a suitable elastomer.

In still another method of making a mud motor, a mandrel is formed with a contoured outer surface that substantially corresponds to  
15 the inverse of the desired inner profile of the stator. The contoured outer surface of the mandrel is made of a frangible material, such as ceramic. The mandrel is designed to account for the load and shrinkage of the formed section of the stator. The mandrel is sprayed with a suitable metal to a desired thickness to form a tubular member. The mandrel is  
20 then removed from the tubular member. The resulting tubular member has the desired inside profile of the stator which is then lined with an elastomeric material.

In each of the methods described above, the elastomeric material is preferably injection molded over the inner surface of the tubular member. Alternatively, the rotor may have an outer elastomeric or  
5 ceramic layer or both the rotor and stator may have metal-to-metal contacting surfaces.

Examples of the more important features of the invention thus have been summarized rather broadly in order that the detailed  
10 description thereof that follows may be better understood, and in order that the contributions to the art may be appreciated. There are, of course, additional features of the invention that will be described hereinafter and which will form the subject of the claims appended hereto.

15

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

For detailed understanding of the present invention, reference should be made to the following detailed description of the preferred  
20 embodiment, taken in conjunction with the accompanying drawings, in which like elements have been given like numerals and wherein:



FIGS. 1A and 1B show a longitudinal cross-section of a mud motor.

FIGS. 2A and 2B show elevational views of a preferred system for making the stator housing according to one method of the present invention.

FIG. 3 shows a cross-section of the stator housing made by the methods of the present invention.

10

FIGS. 4 show an elevational view of a rotary system for making the stator housing according to one method of the present invention.

FIG. 5 shows an elevational view of a swaging process for making the stator housing according to one method of the present invention.

FIG. 6 shows an elevational view of a spraying process for making the stator housing according to one method of the present invention.

FIG. 6A is a cross-section of a mandrel for use in the process of FIG. 6.

FIG. 6B is a cross-section of a mandrel for use in the process of FIG. 6.

### DESCRIPTION OF THE PREFERRED EMBODIMENT

5

The present invention provides methods of making mud motors. In general, the stator is made according to the methods of this invention. A suitable rotor is disposed in the stator to form the mud motor. Before describing the methods of making the mud motors according to the present invention, it is considered helpful to first describe an example of a commonly utilized mud motor for drilling oilfield wellbores.

FIGS. 1A-1B show a cross-sectional elevation of a positive displacement motor 10 having a power section 1 and a bearing assembly 2. The power section 10 contains an elongated metal housing 4, having therein an elastomeric member 5 which has a helically-lobed (lobed) inner surface 8. The elastomeric member 6 is secured inside the housing 4, usually by bonding the elastomeric member 5 within the interior of the housing 4. For the purposes of this disclosure, the combination 6 or the assembly of the elastomeric member 5 and the housing 4 is referred to herein as the "stator."

A rotor 11, preferably made from steel, having a helically-lobed outer surface 12, is rotatably disposed inside the stator 6. The rotor 11 preferably has a non-through bore 14 that terminates at 16 below the upper end 18 of the rotor 11 as shown in FIG. 1A. The bore 14 remains  
5 in fluid communication with the drilling mud 40 below the rotor 11 via a port 20. Both the rotor lobe 12 and the stator lobe 8 profiles are similar, with the rotor 11 having one less lobe than the stator 6. The rotor lobes 12 and the stator lobes 8 and their helical angles are such that the rotor 11 and the stator 6 seal at discrete intervals resulting in the creation of  
10 axial fluid chambers or cavities 26 which are filled by the pressurized drilling fluid 40.

The action of the pressurized circulating drilling mud 40 flowing from the top 30 to the bottom 32 of the power section 1, as shown by  
15 arrow 34, causes the rotor 11 to rotate within the stator 6. Modification of lobe numbers and geometry provide for variation of motor 10 input and output characteristics to accommodate different drilling operations requirements. The rotor 6 is coupled to a flexible shaft 50, which connects to a rotatable drive shaft 52 in the bearing assembly 2 that  
20 carries the drill bit (not shown) in a suitable bit box 54.

The methods of making mud motors according to the present invention will now be described with reference to FIGS. 2A-6A. FIG. 2A shows a method of making a stator by what is referred to herein as the "short stroke" rolling process or method 110. FIG. 2B shows a method of making a stator by what is referred to herein as the "long stroke" rolling process or method 150. To make a stator, such as stator 6 of FIG. 1A, a rigid mandrel 132 is disposed in a tubular member 130 made from a suitable material, such as steel. Tubular member 130 has initial outside and inside diameters of  $d_o$  and  $d_i$  respectively. The mandrel 132 has an outer contoured surface 134, which corresponds to the inverse of the desired contour of the finished stator housing 140. The mandrel 132 is tapered from the front end 138 to the terminating end 136, with the outer dimensions at the end 136 being less than those at the end 138. Tapered mandrel 132 enables easy removal of the mandrel 132 from the finished stator housing 140.

To form the stator housing 140, the tubular member 130 with the mandrel 132 suitably disposed therein is placed between rollers 115a and 115b of the system 110. The rollers 115a and 115b are substantially identical and, therefore, the construction of only the roller 115a is described herein. The roller 115a includes a roller die 112a that strokes or reciprocates in the directions shown by the arrow 108a. The roller

115a urges against the tubular member 130 as it strokes over the tubular member 130. A caliper section 125a defines the travel (depth) of the roller die 112a toward the tubular member 130. The clearance 126a between the roller die 112a and the periphery 127a of the caliper section 5 125a increases from the roller die end 128a to the roller die end 129a, which enables the roller die 112a to travel to a greater depth at the end 128a than the end 129a. Element 149a defines the axis 147 of the movement of the roller die 112a. As noted above, the roller 115b is identical to the roller 115a, in that it has a roller die 112b, a roller caliper section 125b, and a pivot 118b. The roller 115b reciprocates along the 10 pivot 116b in the directions shown by the arrows 108b in the same direction as the die 112a.

In operations, the roller dies 112a and 112b urge against the 15 tubular member 130 and respectively reciprocate (or stroke) over the tubular member 130 along the longitudinal axis 131 of the tubular member 130. The roller dies 112a and 112b travel to greater depths when they stroke toward ends 128a and 128b respectively compared to the ends 129a and 129b. The stator housing 140 therefore finishes 20 toward the right side of FIG. 2A. The tubular member 130 also step wise rotates about its longitudinal axis 131 as shown by arrows 135. The roller dies 112a and 112b compress the tubular member 130 toward the

mandrel 132. As this process continues, the inside of the tubular member 130 presses against the mandrel 132 and starts to acquire the lobed contour 134 of the mandrel 132. Continuing the process causes the tubular member inside 134 to attain the lobed contour with diameter  $d_i'$ . The outer surface 130a retains a tubular form with the diameter  $d_o'$ , which is less than the original diameter  $d_o$  of the tubular member 130. As a portion of the tubular member 130 is formed to the required dimensions, the tubular member 130 is advanced to continue forming the remaining portion of the tubular member 130 into the desired form. A continuous stator housing 140 of any suitable length can be made by this method. The process 110 may be hot-rolled or cold-rolled. Relatively precise stators can be formed with the cold-rolled process. Such stator housings 140 require relatively little or no further machining.

FIG. 2B is a schematic illustrating the long stroke method 150 of making the stator housing 140. The process 150 of FIG. 2B differs from the process shown in FIG. 2A in that the roller dies 152a and 152b have longer strokes compared to the strokes of the roller dies 112a and 112b of FIG. 2A. As seen in FIG. 2B, the stroke of the roller die 152a is defined by the distance between points 154a and 154a' while the stroke of the roller die 152b is defined by the distance between 154b and 154b'. Otherwise the process 150 of FIG. 2A is similar to that of the

process 110 of FIG. 2A. After the stator housing 140 has been formed to a sufficient length, it is cut to the desired length.

FIG. 3 shows the cross-section of an exemplary stator housing 5 250 made according to the processes shown in FIGS. 2A and 2B. The stator housing 250 is shown to have a desired inner contoured profile. The stator housing 250 is then lined with a suitable elastomeric material 254, preferably by a suitable injection molding process. Due to the relatively uniform inner profile 252 of the stator, the elastomeric liner 252 10 is of uniform thickness (relatively) compared to the varying thickness elastomeric liner 5 shown in FIG. 1A. Relatively thin uniform thickness stator liners allow uniform heat dissipation. Metals, such as steel, utilized for making the stator housing 250, are excellent heat dissipators compared to elastomers.

15

FIGS. 4 shows a rolling process 300 for forming a stator housing 310 having an inner lobed profile 312 according to one of the methods of the present invention. The system 300 includes a plurality of radially disposed rollers 320a, 320b and 320c. Each such roller is adapted to 20 rotate in a common direction, i.e., clockwise or counterclockwise. As an example, the rollers 320a-320c are shown rotating counterclockwise as shown by the arrows 322. To form the stator housing 310, a tubular

member 305 with initial desired inner and outer diameters, is fed between the rollers 320a-320c. Each roller 320-320c urges against or exerts pressure on the tubular member 310 as shown by arrows 326 while the rollers 320a-320c rotate. A mandrel 315 having a lobed outer surface 316 is disposed in the tubular member 305. The profile of the surface 312 is reverse of the desired inner profile of the finished stator housing 310. The mandrel 315 is tapered as described above with reference to FIG. 1A for easy retrieval of the mandrel 315 from the finished stator housing 310.

10

To form the stator housing 310, the metallic tubular member 305 containing the metallic mandrel 315 is placed between the rollers 320a-320c. The rollers 320a-320c rotate in the direction 322 while urging against the tubular member 305 in the direction 326. The action of the rotors 320a-320c rotates the tubular member 305 in the direction 328 and gradually reduces the overall diameter of the tubular member 305. This action causes the inside of the tubular member 305 to attain a profile defined by the outer profile 312 of the mandrel 315. When a portion of the tubular member 305 attains the desired inner profile and the outer dimensions, the tubular member 305 is advanced with the mandrel remaining at its position to continue the process of forming the stator housing 310. Accordingly, the method 300 enables transforming a

20



continuous tubular member 305 into a stator housing of any desired length. The stator housing 310 is then cut to the desired length and lined with a suitable elastomeric material as described above with respect to FIG. 3. The rolling process 300 of FIG. 4 is continuous. It may be a cold-rolled or hot-rolled process. The cold-rolled process is preferred because it can be controlled to produce relatively precision-finished stator housings 310, which usually do not require additional machining steps. The hot-rolled process utilizes a hot tubular member. This process is faster than the cold-rolled process, but it is more difficult to control and, in certain cases, the finished stator housing 310 may require additional machining operations.

FIG. 5 shows an elevational view of a rotary swaging process 370 for making the stator housing according to one method of the present invention. A tubular member 350 having a mandrel 352 with a desired outer profile 354 is placed between a plurality of conforming blocks 360a-360d. Each of the blocks 360a-360c has corresponding concave interior surfaces 362a-362c. To form the stator housing, the blocks 360a-360c are alternately urged against the tubular member 350, i.e., in the directional shown by arrows 364 and moved away from the tubular member 350. The tubular member 350 or the blocks 360a-360c or both may be rotated as desired. As this process continues, the outside and

inside diameters of the tubular member 350 continue to reduce, eventually causing the inside 350a of the tubular member 350 to attain the profile defined by the outer profile 354 of the mandrel 352. When a section of the tubular member 350 is formed into the desired shape, the tubular member 350 is advanced (moved forward) and the process continued. The mandrel is tapered for easy removal from the tubular member. The finished stator housing is then lined inside with an elastomeric material as described above with respect to FIG. 3.

FIG. 6 shows an elevational view of a spray forming process for making the stator housing 420 according to one method of the present invention. A mandrel 410 with a predetermined length "L" and an outer profile 414 is fabricated by any known method. The mandrel 414 is made from a frangible material such as ceramic. Alternatively, the mandrel 414 may be made of any stiff material with an outer layer made from a frangible material. The mandrel 414 is then uniformly sprayed with a suitable metal material 418 until it attains a desired diameter "d" 422. In the preferred method, a gas-atomized stream 419 of a suitable molten metal is sprayed on the rotating and advancing mandrel 410. The sprayed metal 418 rapidly solidifies. The stator housings 420 made by the spray forming process 400 are usually fine grained and substantially free from segregation effects.

The spray forming process 400 is preferably achieved by gas-atomizing the molten metal 418 from a source 434 thereof into a spray 419 and depositing the spray 419 on the mandrel 410. The deposition rate of the spray 429 is preferably controlled by a vacuum system 430. This allows forming a layer of semi-solid/semi-liquid metal of controlled thickness. After the stator housing 420 has been formed, the mandrel is dislodged from within the stator housing 420 by discarding the frangible material. The inner surface 414 of the stator housing 410 is then lined with a suitable material as described in reference to FIG. 3. The material 418 may be sprayed in the form of layers, wherein adjacent layers having the same or different material. For example the first layer may be of tungsten carbide and the next layer may be of steel. The choice of materials will depend upon the physical characteristics desired of the finished product, such as ductility and strength.

Alternatively, the mandrel 410 may be made as a hollow liner 440 having the inner dimensions and profile 442 desired of the finished stator housing 420. FIG. 6A shows a cross-section of a hollow mandrel 450 for use in the spray method 400 of FIG. 6. The mandrel 450 has an inner surface 452 that defines the contour of the stator inside. The outer surface 454 may be of any type. The mandrel thickness 456 may be

relatively small. FIG. 6B shows a cross-section of a mandrel 460 that has the inner profile 462 that defines the inner profile of the stator and has a tubular outer profile 464. The mandrels 450 and 460 are relatively inexpensive and easy to make. The inside surface of the mandrels 450  
5 and 460 may be made in the finished form of the stator inside prior to or after the spraying of the mandrels with the suitable material. This may be lined with a suitable elastomer or may be a metallic surface.

The stator housing made by any of the methods of the present  
10 invention may be coated or lined with any suitable material, including an elastomeric material, a thermo-plastic material, a ceramic material, and a metallic material. Any suitable method or process may be utilized to apply such materials to the stator housing. The processes utilized may include a galvanic deposition process, (ii) an electrolytic deposition  
15 process, (iii) a molding process, (iv) a baking process, (v) a plasma spray process, and (vi) a thermo-set process. The process utilized will depend upon the type of the material selected. The rotor may also be lined with a suitable material or rotor and stator may have metal-to-metal contacting surfaces.

20

The foregoing description is directed to a particular embodiment of the present invention for the purpose of illustration and explanation. It

WO 99/31389

PCT/US98/26963

will be apparent, however, to one skilled in the art that many modifications and changes to the embodiment set forth above are possible without departing from the scope and the spirit of the invention.

It is intended that the following claims be interpreted to embrace all such  
5 modifications and changes.



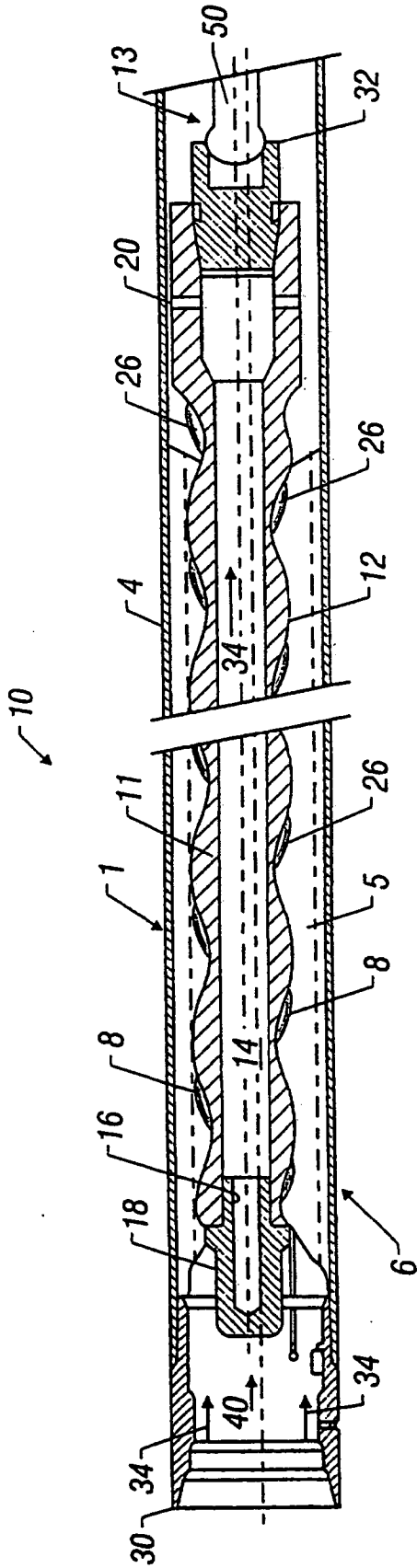


FIG. 1A

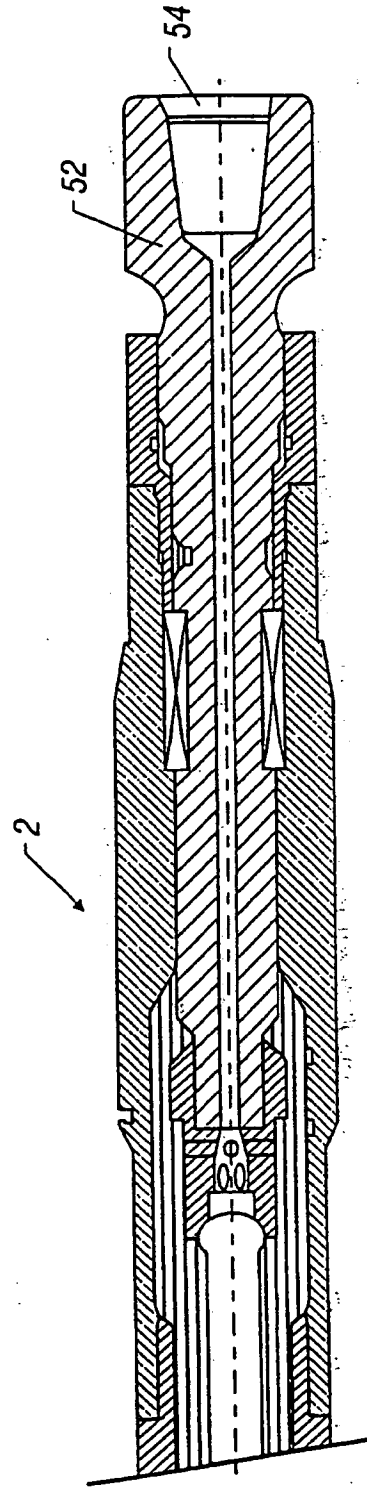


FIG. 1B

2/6

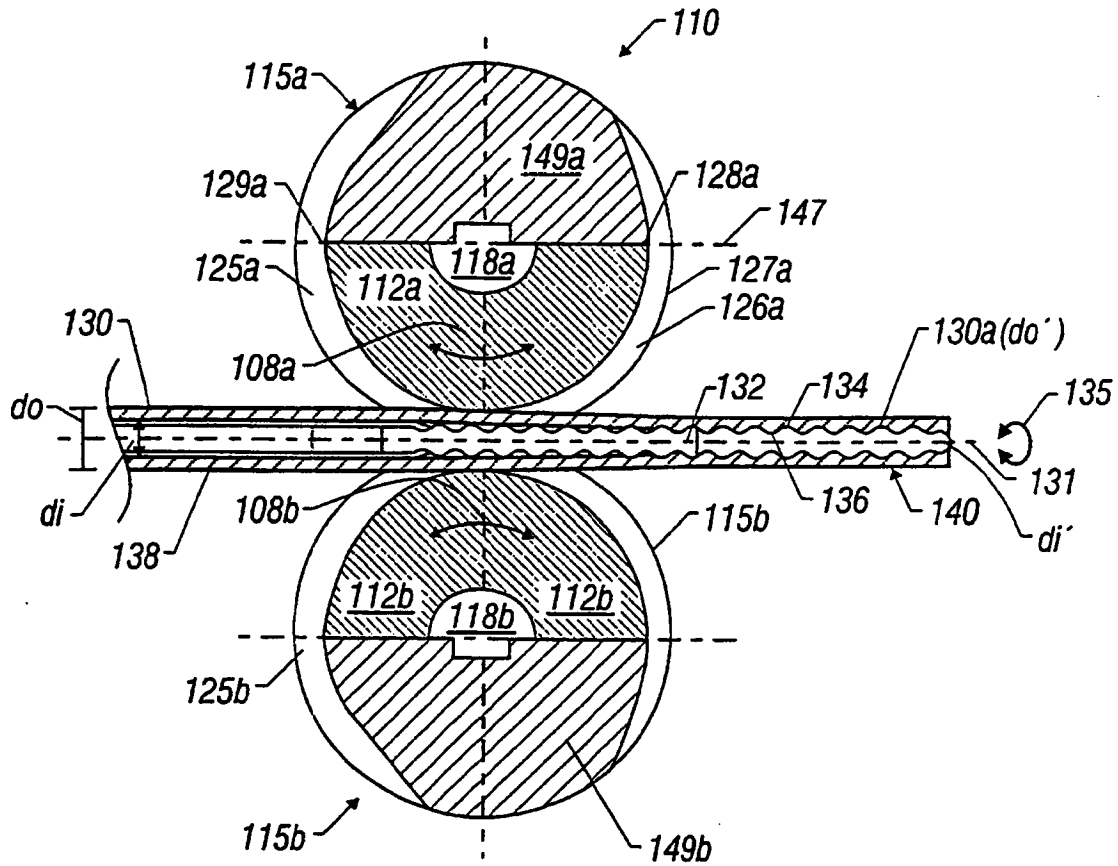


FIG. 2A



3/6

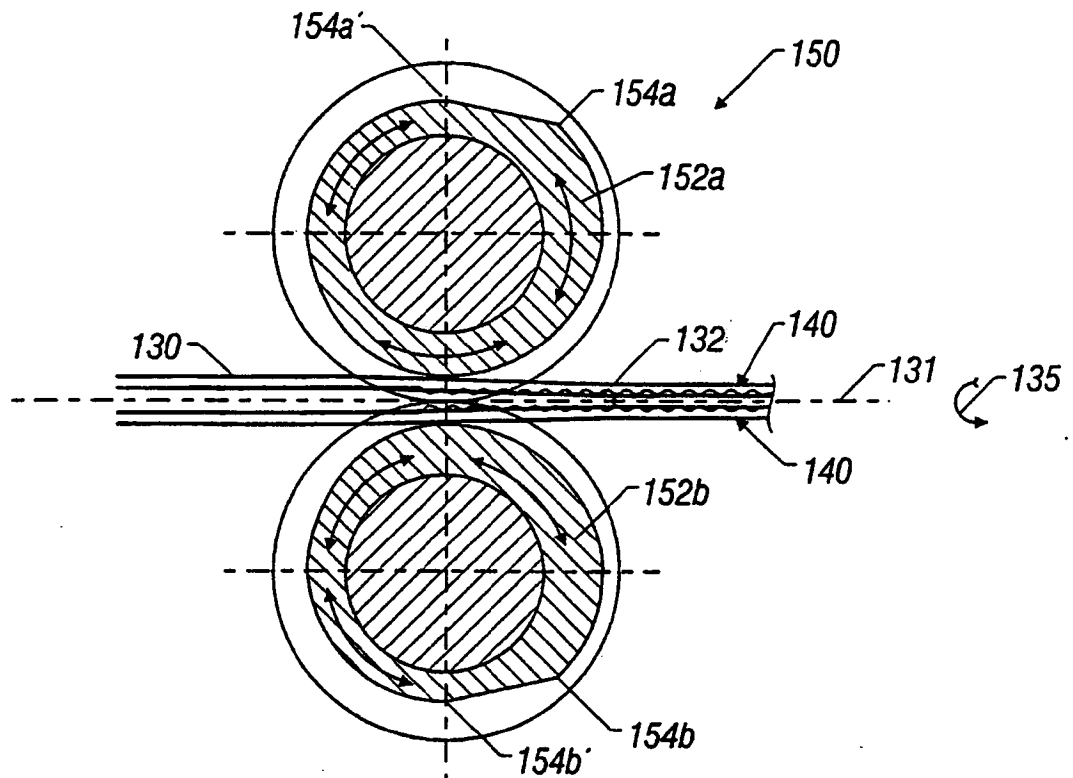


FIG. 2B

4/6

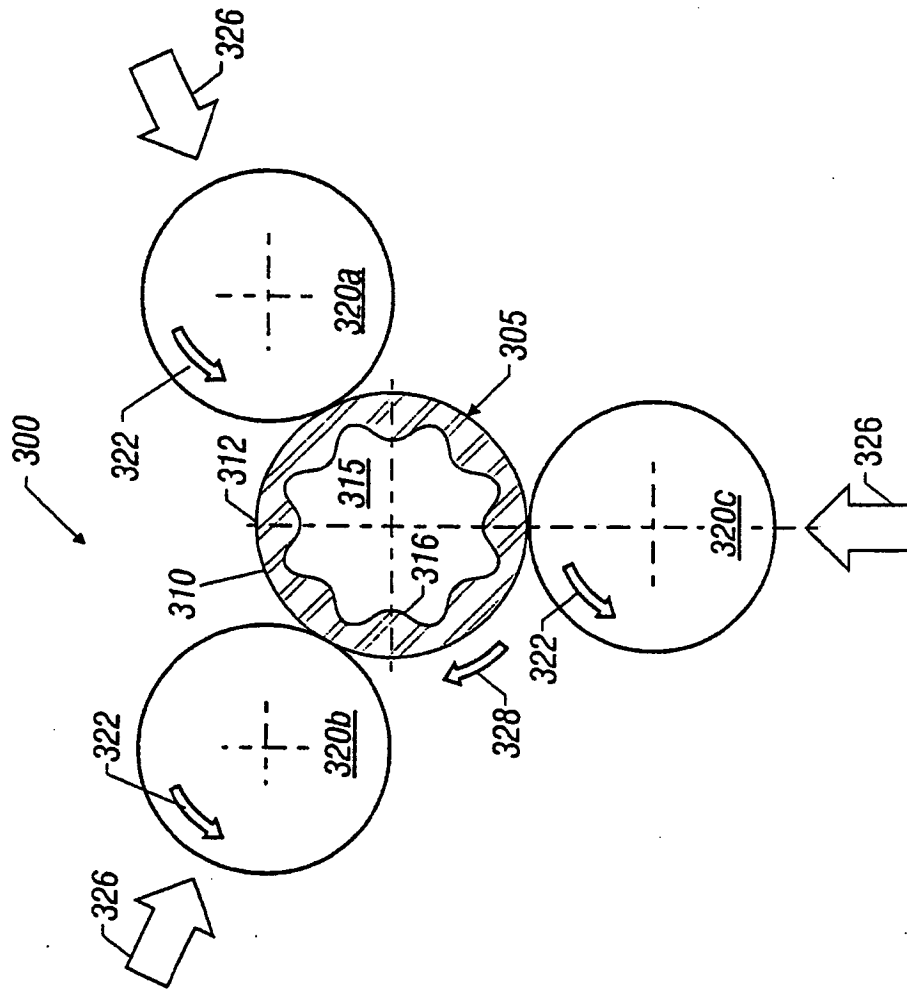


FIG. 4

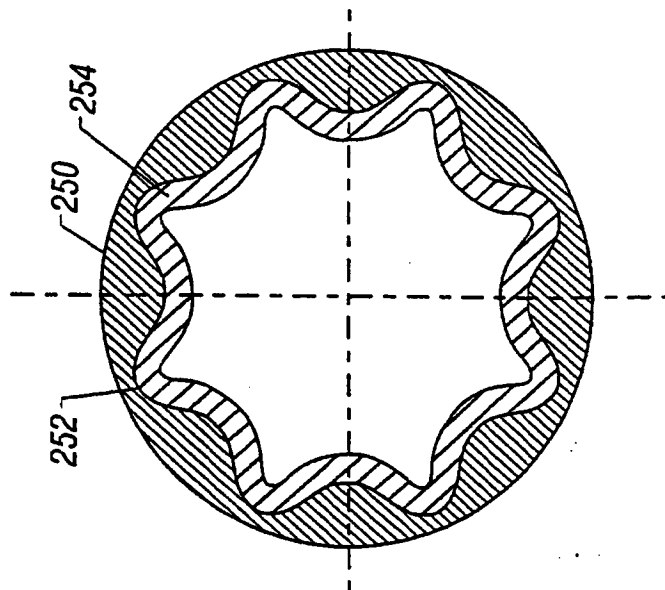


FIG. 3

5/6

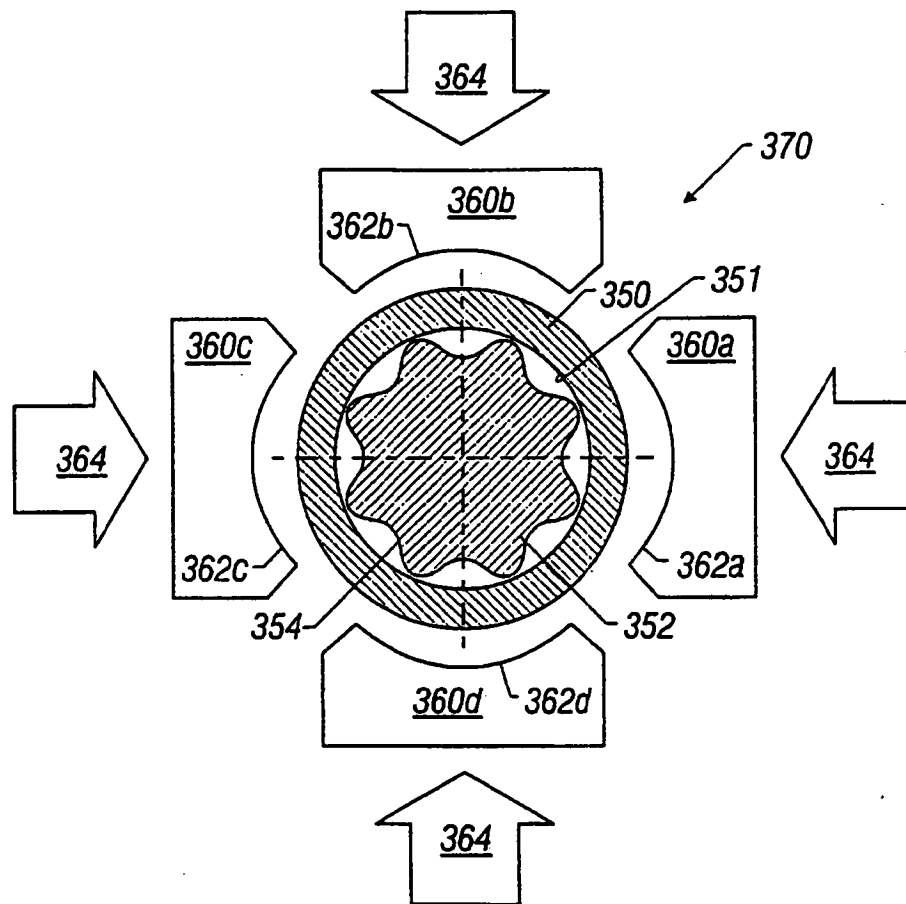


FIG. 5

6/6

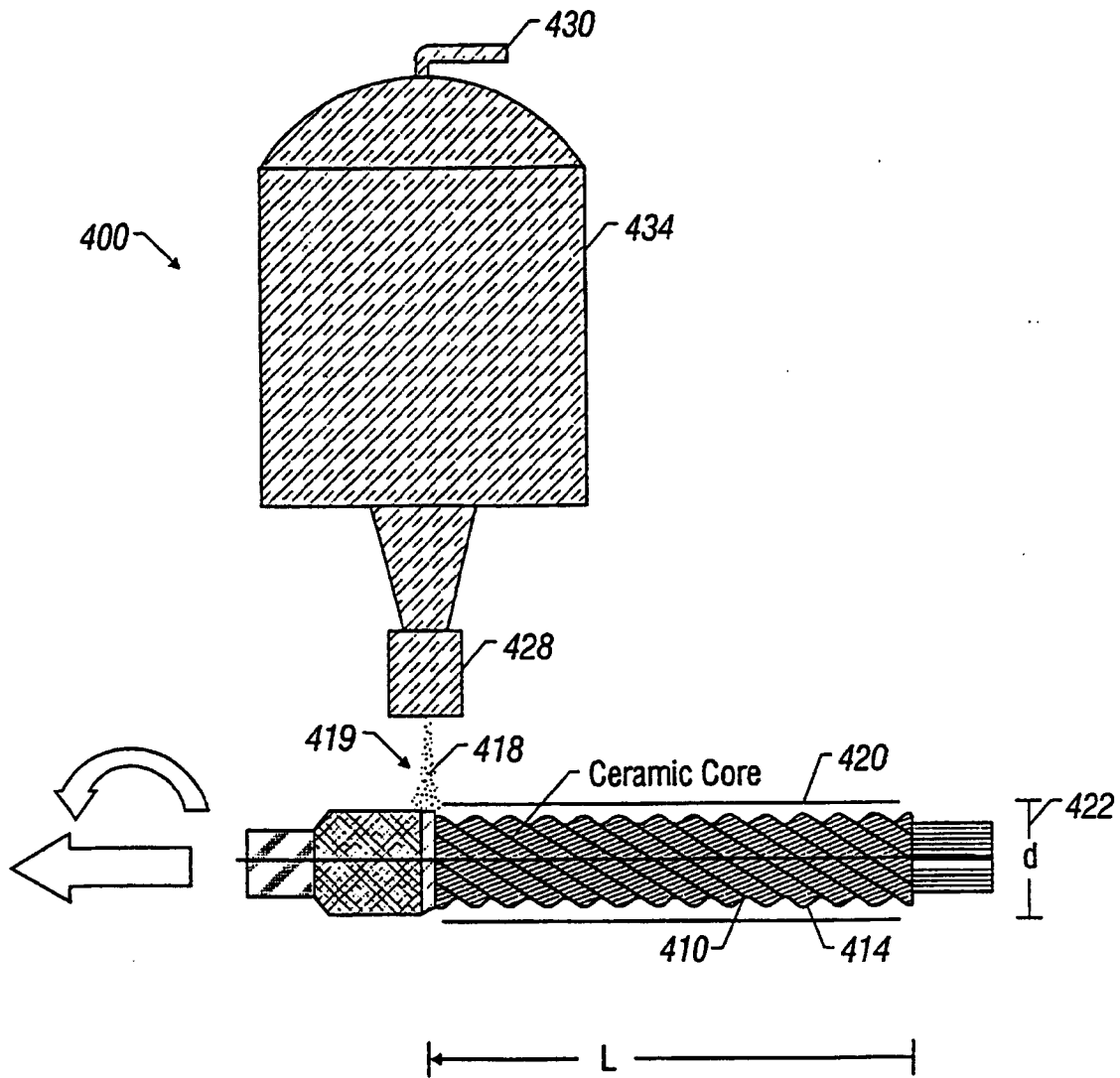


FIG. 6

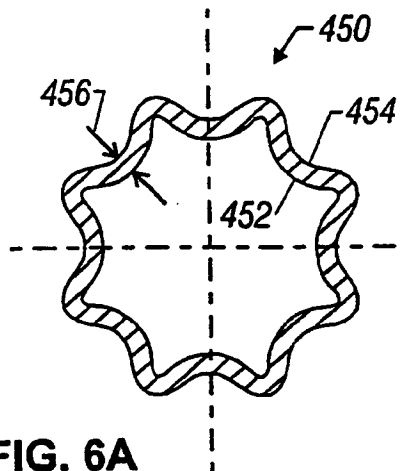


FIG. 6A

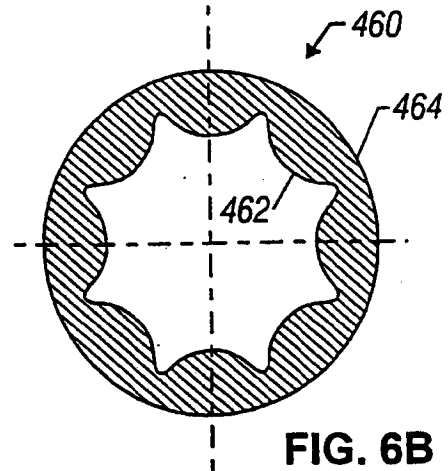
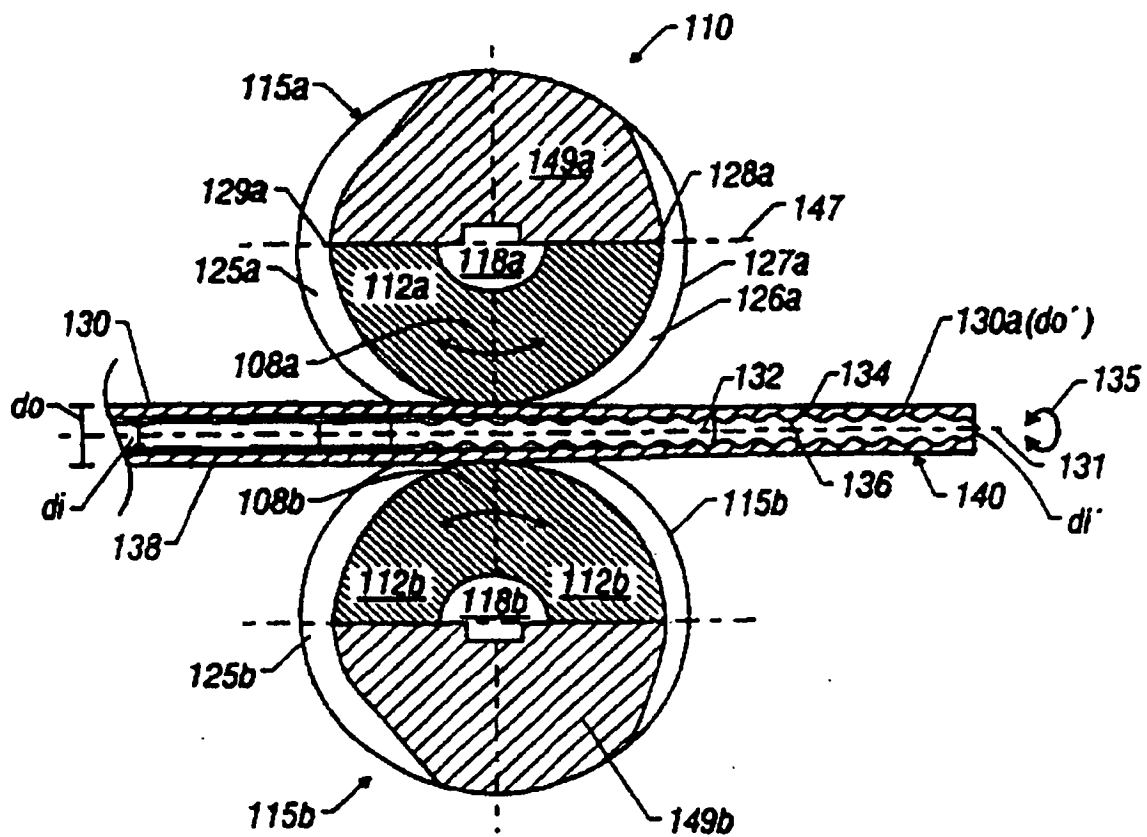


FIG. 6B



**THIS PAGE BLANK (USPTO)**